

XVI. Space Simulation

ENVIRONMENTAL SCIENCES DIVISION

A. Holographic Study of Operating Compact-Arc Lamp, C. G. Miller and C. L. Youngberg

1. Introduction

Solar heatloads on spacecraft are simulated by using the radiation from xenon compact-arc lamps and causing the radiation to impinge in a nearly parallel beam on the structure under study. In order to get enough intensity in a nearly parallel beam whose divergence approaches that of sunlight at earth's orbit (32 sec of arc), the xenon compact-arc lamp must be operated at the material and structural physical limits for highest luminous output and brightness. In order to design to the material limits, we are interested in efficient heat transfer by fluids. The fluids involved are the pressurized xenon gas which transfers heat convectively, and the water flow which cools the interior of the cathode and anode of the lamp. Heat fluxes at the anode of an operating lamp are about 2×10^7 Btu hr⁻¹F⁻¹ft⁻² and to design for such high rates, we need to know the mode of action of gaseous convective cooling, and of liquid heat transfer inside the water-cooled elements of the lamp.

Double exposure holographic techniques are used to determine the conditions in the gas stream between the cathode and the anode of an operating lamp.

2. Arc Characteristics of Concern

The molecular density in the arc discharge column is the quantity of great importance in the understanding and utilization of compact-arc lamps. While the gas pres-

sure in the lamp is 12 atm when the arc is burning, having started from 4 atm cold, the arc core itself is at a temperature of 6000°K, and thus the particle density is only 1.7×10^{19} molecules cm⁻³ at 12 atm, virtually the same as for a gas at 1 atm and room temperature.

The appearance of an operating arc (Fig. 1) shows the well-developed center core of highest radiance, and the surrounding arc sheath, which is also luminous, and whose outer edges are sharply defined in the pressure regime above atmospheric.

It is reasonable to consider the luminous core as the locus of high temperature, and thus low density partly ionized gas. Because of the great mobility of electrons compared to that of positive ions, ion pairs formed in the center core should lose their electrons faster than their positive ions, and thus the core has a net positive makeup, while the surrounding arc sheath should have a net negative charge.

A separate experiment, done for another purpose and previously reported (SPS 37-63, Vol. III, pp. 161-166), used a lamp with magnets external to the body as shown in Fig. 2. The magnets were powered by ac and caused the arc flame to move back and forth in the $\mathbf{j} \times \mathbf{B}$ direction.

High-speed motion pictures of the back-and-forth motion of the arc brush and core caused by the arc currents interacting with the time-varying magnetic field of the



Fig. 1. Representative operating arc

magnets (shown in Fig. 2) showed that the brush and core were deflected in opposite directions upon application of varying magnetic fields, the core responding as though there were a resistive viscous force. This is consonant with the view that the cathode core is a predominantly positive ion stream, traveling from cathode to anode against the electric field by momentum transfer from the electron stream, and that the brush is predominantly negatively charged. An interferometric method to determine density profiles across the discharge gap would be valuable to support the physical picture developed here.

Another important aspect of the arc discharge concerns the hot gas flow about the anode. For highest heat transfer rates, it is desirable to develop turbulent flow and an interferometric method of examination should also be useful here.

3. Holographic Interferometry to Measure Aerodynamic Quantities

A means to examine the problem mentioned in the preceding subsection is at hand in the method of flash

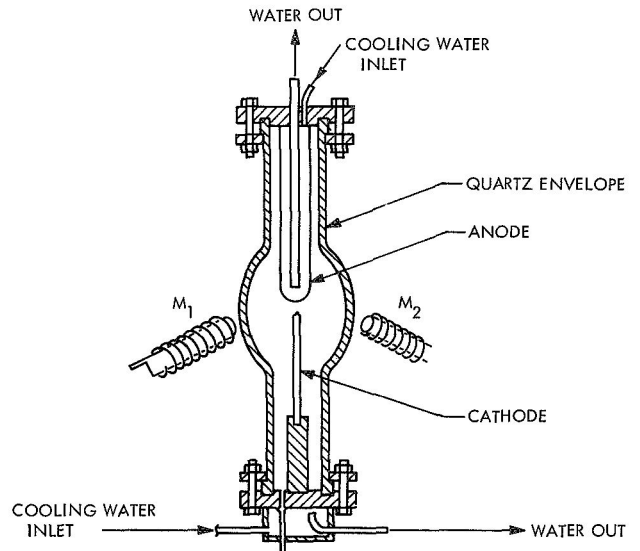


Fig. 2. Arrangement of magnets to deflect arc

holographic interferometry. In this method (Ref. 1), the interferometer uses a common optical path in which beam separation is achieved by two exposures separated in time. This method allows a great relaxation in the usual interferometry requirements for accurate alignments and precision optical elements, and gives a complete three-dimensional record of the interference phenomenon, permitting post-exposure focusing and examination from various directions.

Such a system was used to examine an operating arc in this laboratory. The experimental details have been described elsewhere (Ref. 2). We will not repeat the experimental details here but will discuss the limitations on the use of information derived from flash holograms and the results of the experiments done in regard to the physical picture developed in *Subsection 2*.

Reference 3 discusses some sensitivity factors in plasma diagnostics, which are summarized below.

- (1) Optical quality of the lamp and windows may be low and still result in interferograms. Thus, actual lamp bodies may be employed.
- (2) Relative motion of parts of the objects of interest can completely obscure the results. Thus, the small relative motion caused by turbulence of the cooling water inside the cathode and anode of the lamp completely obscure the interferogram. It was

necessary to use a special lamp termed Variarc in which the electrodes are mounted very securely to minimize this difficulty.

- (3) The holographic method is insensitive to intrinsic plasma radiation. Since the plasma radiation is incoherent, it does not contribute to the formation of the hologram, but only leads to some illumination of the hologram, and degradation of contrast. In our case, the use of narrow band interference filters centered on the laser wavelength retained the contrast by suppressing most of the plasma illumination from the photographic film.
- (4) The holographic interferometry method has the same sensitivity as normal interference measurements. It is difficult to detect path differences smaller than $\lambda/10$ or greater than, say, 100λ .
- (5) In the general case, far from absorption lines, the refraction of the plasma is given by

$$n - 1 = \left(A + \frac{B}{\lambda^2} \right) N_a - \left(\frac{e^2}{2 m \epsilon_0} \frac{1}{\omega_0^2 - \omega^2} \right) N_e$$

where N_a denotes the density of atoms, N_e denotes the density of electrons, and n is the index of refraction.

Using Cauchy's formula values of A and B for noble gases, we find that the gas refraction is comparable in magnitude to the refraction of an electron gas at a particle density

$$N_a/N_e \sim 10$$

Now changes in the optical path length of the order of $\lambda/10$ (in a layer thickness of 1 cm and with $\lambda = 0.5 \mu$) correspond to electron densities of $5 \times 10^{16} \text{ cm}^{-3}$, and atom densities of $5 \times 10^{17} \text{ cm}^{-3}$.

We should thus be able to distinguish density variations of 3% (from the $1.7 \times 10^{19} \text{ atoms cm}^{-3}$ found in Subsection 2) at the $\lambda/10$ criterion, or density variations of 30% at a 1λ criterion.

To show that this should not be obscured by a decrease in refraction due to electrons, we note that from Saha's equation:

$$\frac{px^2}{1-x^2} = 3.16 (10^{-7}) T^2 \sqrt{T} \exp \left(\frac{-eV_i}{kT} \right)$$

which gives the degree of ionization x prevailing in a gas in thermal equilibrium at $T^\circ\text{K}$, and where p is the pressure in atmospheres, and V_i is the ionization potential of the gas. The electron density is $(x) (1.7 \times 10^{19})$ or $1.7 \times 10^{16} \text{ electrons cm}^{-3}$, or only one third the number needed for the $\lambda/10$ criterion.

4. Interpretations of Holograms

A double flash hologram made of an operating Variarc (Fig. 3) shows no evidence of gas density variation in the vicinity of the center core, and no evidence of a highly localized region of very low density gas. Furthermore, an examination of the anode area appears to show no turbulence developed at the arc stream-anode interface. Such turbulence would be desirable to increase heat transfer rates.

Figure 4 shows a double exposure of an operating arc with an interval of about 2 min between exposures. The

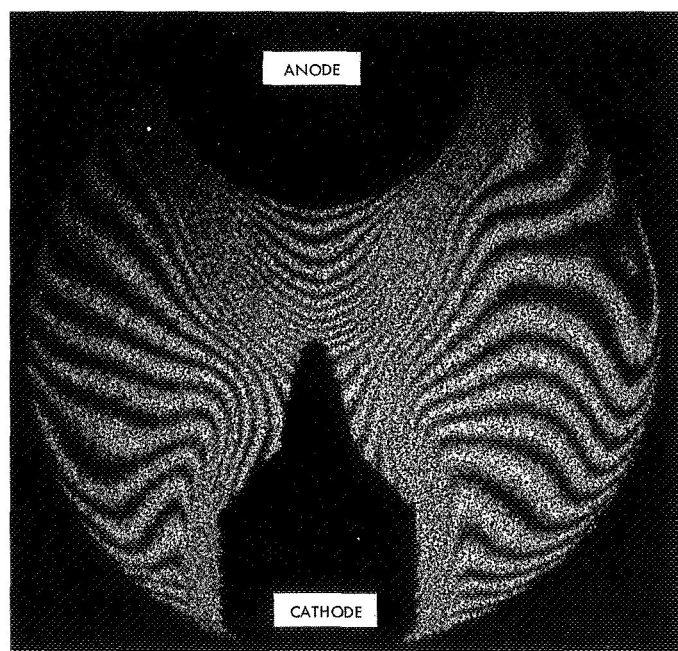


Fig. 3. Hologram of operating arc

purpose was to investigate the random variations in density within a continually operating lamp. The fringe pattern is nondescript, implying no long-term stability in the gas flow pattern.



Fig. 4. Double flash hologram with long interval between exposures



Fig. 5. Asymmetric pattern of arc with imposed magnetic field

Figure 5 is a hologram reconstruction of an interferogram in which a magnetic field was introduced to deflect the arc. The interference fringes show a nonsymmetrical pattern in agreement with the visual observation that the magnetic field did deflect the arc.

Finally, Fig. 6 shows a hologram reconstruction of an interferogram of an operating lamp with a transparent grid placed on the holocamera diffuser, considerably behind the plane of the arc discharge. In the photograph, the camera is focused on this grid, and is looking through the arc. The electrodes are out of focus. The intent of this hologram was to determine if there was significant refraction by the arc. The lack of distortion of the grid lines indicate that there was not.

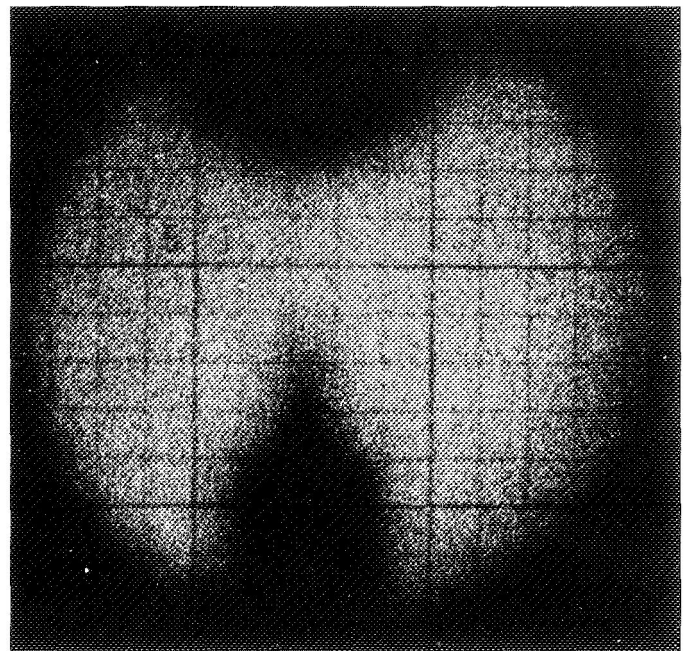


Fig. 6. Hologram focused on grid pattern behind lamp showing no significant refraction by arc stream

References

1. Heflinger, L. O., Wuerker, R. F., and Brooks, R. E., "Holographic Interferometry," *J. Appl. Phys.*, Vol. 37, pp. 642-649, 1966.
2. Miller, C. G., and Stephens, J. B., "Flash Holography Applied to Fluid Heat-Transfer Phenomena," in *Holographic Instrumentation Applications*, NASA SP-248, National Aeronautics and Space Administration, Washington, 1970.
3. Zaidel, A. N., Ostrovskaya, G. V., and Ostrovskii, Yu. I., "Plasma Diagnostics by Holography (Review)," *Sov. Phys.-Tech. Phys.*, Vol. 13, pp. 1153-1163, 1969.